Combined Plasmonic Gratings in Thin Organic Solar Cells

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Abstract

Thin-film solar cells promise cheaper devices, but they inherently present a major light-trapping challenge, especially in ultra-thin layers, when light should be absorbed in layers of only tens of nanometer thick. Then the sub-wavelength capabilities of metallic structures make a large difference, by exploiting strongly confined plasmonic resonances. An ultimate light-trapping structure will exploit the interplay between different design features, so that a broadband combined enhancement is achieved. Here we propose a design with metallic gratings both on the top and bottom side of the cell. Single gratings were shown to provide absorption enhancement in certain wavelength ranges, but here we optimize their individual and combined features to obtain a more global, broadband device. It is clear both gratings have different goals: the top grating should reduce reflectivity, whereas the bottom grating should reflect diffusely as much as possible. Additionally, in combining the two gratings we aim to at least superpose the individual enhancements, indicating that the relative grating positioning needs careful examination. To map the enhancement we perform rigorous simulations for a thin organic active layer of 50nm P3HT:PCBM, sandwiched between silver gratings: a front grating with metal wires, and a bottom grating of ridges on a metal surface. First we analyze the gratings separately, and find a complex coupling between localized and propagating modes, that is elucidated by Bloch dispersion diagrams. Crucially, incident-angle dependent calculations present the so-called dark modes, which do not show up in traditional perpendicular-incidence calculations. For the combined grating case, we introduce an offset between both gratings. This results in highly efficient structures, where the individual enhancement areas are complementing each other. Ultimately, we obtain an enhancement factor of 1.4 (integrated absorption: 48% to 67%). In addition, the combined structure keeps this efficiency over a much broader angular range than the single gratings separately.

Keywords: plasmonics, light-trapping, gratings, organic solar cells